Rb-Sr AND U-Th-Pb SYSTEMATICS OF BOULDERS 1 AND 7, APOLLO 17. M. Tatsumoto, P. D. Nunes, R. J. Knight, and D. M. Unruh, U. S. Geological Survey, Denver, Colorado 80225

U-Th-Pb analyses of boulder 1 (Wood's consortium), station 2 and Rb-Sr and U-Th-Pb analyses of boulder 7 (Chao's consortium), station 7 are presented, and the early lunar evolution which formed the lunar primitive crust is discussed. The boulders were apparently derived from somewhere in the upper part of the South (boulder 1) and the North (boulder 7) Massifs, and these highland areas were uplifted relative to the Serenitatis basin (1).

Rb-Sr systematics. Clast type 1 (recrystallized olivine-plagioclase microbreccia; sub no. 57) in sample 77135 of the vesicular gray crystalline rock collected from boulder 7 was separated into an olivine-poor part (A) and an olivine-rich part (O). Olivine and plagioclase were separated by heavy liquids and hand-picking from 100-mg-size samples. The Rb-Sr results are presented in Table 1 and Figure 1. A Rb-Sr internal isochron for the olivine-poor part, consisting of plagioclase, olivine, and whole-rock analyses, yields an age of $3.90 \pm 0.03 \times 10^9$ years (2σ) and an initial $^{87}Sr/^{86}Sr$ of 0.69928 ± 0.00004 (2σ). The internal isochron of the olivine-rich clast consists of plagioclase, olivine, and whole-rock samples and yields an age of $3.85 \pm 0.28 \times 10^9$ years (2σ) and an initial $^{87}Sr/^{86}Sr$ ratio of 0.69927 ± 0.00025. The large uncertainty in this age is due to data obtained from the whole rock of the olivine-rich part (Fig. 1) and may reflect either Rb enrichment in the clast at about 3.9 b.y. ago or erroneous data. Nevertheless, the internal isochron age calculated from all clast 1 data is 3.89 ± 0.08 b.y. (2σ) with the initial Sr ratio of 0.69926 ± 0.00008. This age for the clast 1 appears to be slightly older than the ages of Apollo 17 basalts measured by the Rb-Sr method (3.81-3.83×10^9, Birck et al. (2), Chappell et al. (3), Murthy et al. (4), Nyquist et al. (5), Tatsumoto et al. (6); 3.77×10^9 b.y., Tera et al. (7)). We interpret the 3.89-b.y. age as likely reflecting the Serenitatis basin formation and the 3.8-b.y. age as recording the time of basalt flooding of this basin.

Using the lowest determined lunar initial $(^{87}Sr/^{86}Sr)_{LIM} = 0.69885 \pm 0.00004$ of 60015 (8), we calculate model ages of the olivine-poor "whole rock" and olivine-rich "whole rock" of 4.52 and 4.31 b.y., respectively. These model ages only have strict meaning if the assumed $(^{87}Sr/^{86}Sr)_{LIM}$ is truly representative of these samples and the whole rocks have remained closed systems since the calculated age. These data together with the U-Pb upper concordia intercept age discussed below indicate that clast 1 originally formed >4.3 b.y. ago.

U-Th-Pb systematics. The U-Th-Pb results of the matrix (sub no. 73), the black clast (81) and the white clast (117) of sample 72275 of boulder 1, and the less vesicular (33) and the more vesicular (34) parts of the matrix and clast 1 (57A) of sample 77135, and the white clast 77215,37 from boulder 7 are presented in Table 2. Sample 72275 contains a large clast consisting of a light-colored core (white clast, sub no. 117) with a dense dark envelope (black clast, sub no. 81). The black clast was hand-picked to ≥95 percent purity, but the white clast analyzed was only about 80 percent pure white material due to intimate mixing of black specks. The U, Th, and Pb concentrations of the black clast are as high as those of Apollo 12 and 14 KREEP-rich soils and breccias, indicating this clast has a substantial KREEP component. The rather high U, Th, and Pb contents of boulder 1 matrix may also reflect a significant KREEP component. Relatively high U and Pb concentrations in the white clast compared to those in the white clast of boulder 7 are probably due to a significant contribution of black material, as stated above.

Although the preliminary examination (9) indicates that the mineral assemblage (clinopyroxene, ∿65%; plagioclase, ∿20%; olivine, ∿10%; and ilmenite, ∿5%) and texture of the more vesicular and less vesicular parts of 77135 are similar, the U, Th, and Pb concentrations of the more vesicular part are up to three times higher than in the less vesicular part.

The data for boulders 1 and 7 are plotted on a U-Pb concordia diagram in Figure 2. Due to the flatness of concordia around the 3.8- to 4.7-b.y. region, no accurate time assessment can be made from these data alone. The data appear, however, to lie on a 3.85- to 4.55-b.y. discordia line. The lower intercept agrees with the Rb-Sr internal age of

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77135 stated above. The upper intercept appears slightly older than an early lunar differentiation age of 4.47 b.y. (10, 11). Because the boulders are complex breccia, the discordia line may not have strict age significance. However, the data indicate that the boulders include components of very old material (possibly as old as 4.55 b.y.).

Combining U-Th-Pb and Rb-Sr data obtained from Highland site samples, we postulate that the moon accreted ∿4.65 b.y. ago and that the moon's outer portions underwent chemical differentiation within the first 100 to 200 m.y. following accretion, in accord with the hypothesis of Nunes and Tatsumoto (10). The relatively unradiogenic nature of the orange soil (74220) Pb suggests to us that a mafic or ultramafic source exists for this lead beneath the mare basalt source region [120-170 km deep (12)]. Therefore, we like thermal history models for the moon (e.g., 13) which suggest that initial melting of the moon reached depths of several hundred kilometers or more. Considering the lowest reported lunar $(^{87}Sr/^{86}Sr)_{LIM}$ in anorthosite 60015 (8), anorthosite was likely among the first material to crystallize and spottily coat the molten surface as the moon cooled. A significant portion of the lunar crust consists of plagioclase-rich noritic rocks (a plausible source material of KREEP) which must have formed prior to the oldest KREEP rocks (≥4.4 b.y. ago). Similar to early KREEP formation, anorthosites with $(^{87}Sr/^{86}Sr)_I$ values slightly higher than that of 60015 (LIM) may have formed slightly after (∿4.4 b.y. ago?) the postulated primary differentiation ∿4.65 b.y. ago. We postulate from U-Th-Pb data (14) that "granite" 12013 originally formed ∿4.4 b.y. ago and that the 3.9-b.y. internal Rb-Sr isochron age (15) represents a later metamorphic event.

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Table 1. Rb-Sr data for 77135,57.

Sample	Weight (mg)	K (percent)	Rb (ppm)	Sr (ppm)	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
77135,57,0						
Plagioclase	9.9	0.116	2.70	246.1	0.0317	0.70106 ± 7
Whole rock	10.1	0.045	1.33	84.3	0.0457	0.70167 ± 10
Olivine	35.1	0.022	0.81	21.0	0.1107	0.70538 ± 8
77135,57,A						
Plagioclase	15.0	0.109	3.38	208.7	0.0468	0.70188 ± 3
Whole rock	37.4	0.067	2.05	115.8	0.0511	0.70216 ± 16
Olivine	24.5	0.020	0.79	12.5	0.1829	0.70946 ± 2

Our measured value of the NBS standard SRM 987 is Sr^{87}/Sr^{86} = 0.71018 ± 0.00003 (2 standard deviations of mean) during the course of this study.

Table 2. U-Th-Pb data for Boulders 72275 (Wood Consortium) and 77136 and 77215 (Chao Consortium)

Sample no.	P/C	Weight (mg)	Concentration (ppm)* U	Th	Pb	Atomic ratios corrected for analytical blanks** $^{232}Th/^{238}U$	$^{238}U/^{204}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
72275,73 matrix #1	P	162.0+					1,325	1,225	599.3	1,218	0.4893	0.9945
	C_1	131.8	1.561	5.962	3.096	3.945	4,284	3,961	1,905	--	0.4811	--
	C_2	150.0	1.672	6.285	3.451	3.885	4,712	4,556	2,183	--	0.4792	--
72275,81 black clast	P	53.3					1,915	1,937	1,176	1,880	0.6072	0.9705
	C	31.7	3.500	13.21	7.878	3.899	2,493	2,521	1,492	--	0.5918	--
72275,117 white clast	P	83.3					1,473	1,423	818.2	1,347	0.5752	0.9472
	C	50.7	0.670	lost	1.410	--	2,445	2,361	1,360	--	0.5761	--
77215,37 white clast	P	156.5					1,680	1,642	927.0	1,571	0.5645	0.9565
	C	158.4	0.507	1.993	1.079	4.064	1,455	1,422	816.0	--	0.5738	--
77135,57A clast I	P	136.8					1,441	1,353	712.9	1,341	0.5269	0.9913
	C	122.1	0.546	2.136	1.115	4.042	1,191	1,119	589.2	--	0.5265	--
77135,33 less vesicular basalt matrix	P	143.0					1,375	1,310	719.6	1,280	0.5495	0.9775
	C	133.2	0.467	1.863	0.9713	4.119	1,387	1,321	716.5	--	0.5425	--
77135,34 more vesicular basalt matrix	P	198.8					2,584	2,455	1,300	2,361	0.5296	0.9618
	C	125.0	1.390	5.224	2.840	3.882	2,755	2,618	1,385	--	0.5289	--

*Concentration runs were "total spiked" to insure equilibration of spikes and samples.

**Analytical total Pb blanks ranged from 0.8 ng to 1.4 ng.

+Actually only 54 mg were analyzed since 2/3 of solution was spilled. This explains the low radiogenicity of this composition run.

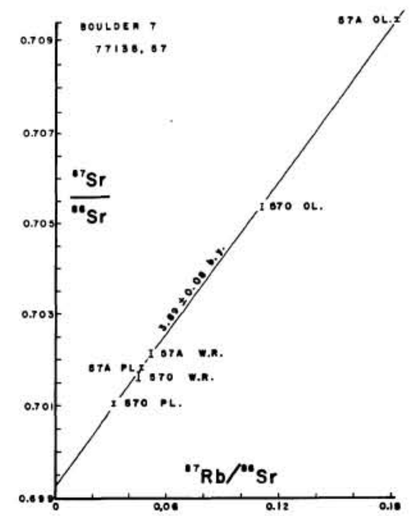

Fig. 1. Isochron age and $(^{87}Sr/^{86}Sr)_i$ are 3.89 ± 0.08 b.y. and 0.69926 ± 0.00004 [2σ (16)], respectively.

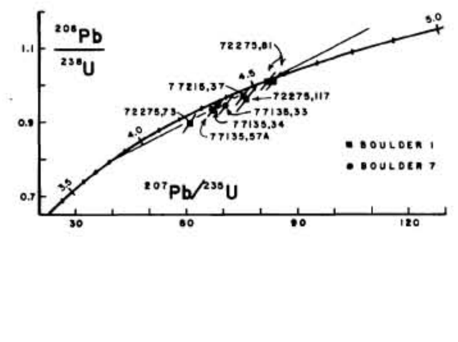

Fig. 2. Apollo 17 boulder samples. Numbers on concordia are in b.y. Data corrected for blank and primordial Pb.